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, D. Knapp, J.A. Newcomer, and J. Cihlar

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Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall, Editor

Volume 98

BOREAS Level-3p Landsat TM Imagery: Geocoded and Scaled At-sensor Radiance

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BOREAS Level-3p Landsat TM Imagery: Geocoded and Scaled At-sensor Radiance

Jaime Nickeson, David Knapp, Jeffrey A. Newcomer, Josef Cihlar

Summary

For BOREAS, the level-3p Landsat TM data were used to supplement the level-3s Landsat TM products. Along with the other remotely sensed images, the Landsat TM images were collected in order to provide spatially extensive information over the primary study areas. This information includes radiant energy, detailed land cover, and biophysical parameter maps such as FPAR and LAI. Although very similar to the level-3s Landsat TM products, the level-3p images were processed with ground control information, which improved the accuracy of the geographic coordinates provided. Geographically, the level-3p images cover the BOREAS NSA and SSA. Temporally, the four images cover the period of 20-Aug-1988 to 07-Jun-1994. Except for the 07-Jun-1994 image, which contains seven bands, the other three contain only three bands.

Note that the level-3p Landsat TM data are not contained on the BOREAS CD-ROM set. An inventory listing file is supplied on the CD-ROM to inform users of the data that were collected. See Sections 15 and 16 for information about how to acquire the data.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-3p Landsat TM Imagery: Geocoded and Scaled At-sensor Radiance

1.2 Data Set Introduction

The BOReal Ecosystem-Atmosphere Study (BOREAS) Staff Science effort covered those activities that were BOREAS community-level activities, or required uniform data collection procedures across sites and time. These activities included the acquisition of the relevant satellite data. Data from the

Landsat Thematic Mapper (TM) instruments on the Landsat satellites were acquired by the Canada Centre for Remote Sensing (CCRS) and provided for use by BOREAS researchers.

1.3 Objective/Purpose

For BOREAS, the Landsat TM imagery, along with the other remotely sensed images, was collected in order to provide spatially extensive information over the primary study areas. This information includes detailed land cover and biophysical parameter maps such as biomass, Fraction of Photosynthetically Active Radiation (FPAR), and Leaf Area Index (LAI).

1.4 Summary of Parameters

Landsat TM level-3p data in the BORIS contains the following parameters:

Original image header information, image coordinates, gains and offsets for each band for at-sensor radiance derivations, image bands 3-5 or 1-7 processed in a precision geocorrected form.

1.5 Discussion

Use and distribution of the level-3p Landsat TM images are subject to copyright restrictions. CCRS and Radarsat International (RSI) granted permission to BOREAS to place a subset of the level-3a Landsat TM images on the BOREAS CD-ROM series; however, none of the level-3p images are included. The level-3p images may not be available for public access. Please see Sections 15 and 16 for further details.

BORIS staff processed the Landsat TM level-3p imagery by:

- Extracting pertinent header information from the level-3p image product and placing it in an American Standard Code for Information Interchange (ASCII) file on disk.
- Reading the information in the ASCII disk file and loading the online data base with pertinent information.

1.6 Related Data Sets

BOREAS Level-3a Landsat TM Imagery: Scaled At-sensor Radiance in BSQ Format
BOREAS Level-3b Landsat TM Imagery: At-sensor Radiance in BSQ Format
BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format
BOREAS Level-3s SPOT Imagery: Scaled At-sensor Radiance in LGSOWG Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

BOREAS Staff Science

2.2 Title of Investigation

BOREAS Staff Science Satellite Data Acquisition Program

2.3 Contact Information

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3. Theory of Measurements

The Landsat series of satellites began with the Earth Resources Technology Satellite (ERTS) launched in July 1972. This satellite was renamed Landsat 1 in 1975 to reflect its primary use as a land resource observatory. Through its onboard instruments, Landsat monitors Earth's mountain ranges, deserts, forests, and crops by measuring the light waves they reflect.

The second generation of Landsat satellites (4 and 5) marked a significant advance in remote sensing through the addition of the more sophisticated TM sensor, with higher spectral and spatial resolution, and faster data processing at a highly automated data processing facility at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) in Greenbelt, MD. For BOREAS, the CCRS receiving station in Prince Albert, Saskatchewan, collected the raw data. Processing of the raw data to the level-3p images was performed with the Geocoded Image Correction System (GICS; Friedel, 1992) at the CCRS facility in Ottawa.

As Landsat's instrument mirrors scan Earth's surface, light enters the instrument optics, where it is focused on specially calibrated detector arrays. Onboard electronics encode the detector voltage as binary digits or bits. These digital image data are then relayed back to Earth to be processed into film and Computer-Compatible Tape (CCT) products, which are subsequently used for Earth resources analysis.

4. Equipment

4.1 Sensor/Instrument Description

The TM sensor system records radiation from seven bands in the electromagnetic spectrum. It has a telescope that directs the incoming radiant flux obtained along a scan line through a scan line collector to the visible and near-infrared focal plane, or to the mid-infrared and thermal-infrared cooled focal plane. The detectors for the visible and near-infrared bands (1 to 4) are four staggered linear arrays, each containing 16 silicon detectors. The two mid-infrared detectors are 16 indium-antimonide cells in a staggered linear array, and the thermal-infrared detector is a four-element array of mercury-cadmium-telluride cells. The spectral regions, band widths, and primary use of each channel are given in the following table:

Channel	Wavelength (µm)	Primary Use
1	0.451 - 0.521	Coastal water mapping, soil vegetation differentiation, deciduous/coniferous differentiation.
2	0.526 - 0.615	Green reflectance by healthy vegetation.
3	0.622 - 0.699	Chlorophyll absorption for plant species differentiation.
4	0.771 - 0.905	Biomass surveys, water body delineation.
5	1.564 - 1.790	Vegetation moisture measurement, snow and cloud differentiation.

6	10.450 - 12.460	Plant heat stress measurement, other thermal mapping.
7	2.083 - 2.351	Hydrothermal mapping.

4.1.1 Collection Environment

The BOREAS Landsat TM level-3p images were acquired through the CCRS. Radiometric corrections and systematic geometric corrections are applied to produce the images in a path-oriented and precision-corrected (level-3p) form. A full TM image contains 6,920 pixels in each of 5,728 lines. Before any geometric corrections, the ground resolution is 30 m for bands 1, 2, 3, 4, 5, and 7 and 120 m for band 6 at nadir. The pixel values of the images can range from 0 to 255. This allows each pixel to be stored in a single-byte field. The level-3p images were processed through the CCRS GICS. The Landsat satellite orbits Earth at an altitude of 705 km.

4.1.2 Source/Platform

Although the majority of the BOREAS Landsat TM imagery was acquired by the instrument onboard Landsat 5, some imagery was obtained with the TM sensor on the Landsat 4 platform.

4.1.3 Source/Platform Mission Objectives

The Landsat TM is designed to respond to and measure both reflected and emitted Earth surface radiation to enable the investigation, survey, inventory, and mapping of Earth's natural resources.

4.1.4 Key Variables

Reflected radiation, emitted radiation, temperature.

4.1.5 Principles of Operation

The TM is a scanning optical sensor operating in the visible and infrared wavelengths. It contains a scan mirror assembly that directly projects the reflected Earth radiation onto detectors arrayed in two focal planes. The TM achieves better image resolution, sharper color separation, and greater in-flight geometric and radiometric accuracy for seven spectral bands simultaneously than the previous generation sensor, the MultiSpectral Scanner (MSS). Data collected by the sensor are beamed back to ground receiving stations for processing.

4.1.6 Sensor/Instrument Measurement Geometry

The TM sensor depends on the forward motion of the spacecraft for the along-track scan and uses moving mirror assembly to scan in the cross-track direction (perpendicular to the spacecraft). The instantaneous field-of-view (IFOV) for each detector from bands 1-5 and band 7 is equivalent to a 30-m square when projected to the ground at nadir; band 6 (the thermal-infrared band) has an IFOV equivalent to a 120-m square at nadir.

4.1.7 Manufacturer of Sensor/Instrument

NASA GSFC
Greenbelt, MD 20771

Hughes Santa Barbara Remote Sensing (SBRS)
Goleta, CA

4.2 Calibration

The internal calibrator, a flex-pivot-mounted shutter assembly, is synchronized with the scan mirror, oscillating at the same 7-Hz frequency. During the turnaround period of the scan mirror, the shutter introduces the calibration source energy and a black direct-current restoration surface into the 100-detector field-of-view (FOV).

The calibration signals for bands 1-5 and 7 are derived from three regulated tungsten-filament lamps. The calibration source for band 6 is a blackbody with three temperature selections, commanded

from the ground. The method for transmitting radiation to the moving calibration shutter allows the tungsten lamps to provide radiation independently and to contribute proportionately to the illumination of all detectors.

4.2.1 Specifications

Band	Radiometric Sensitivity [NE(dP)]*
1	0.8%
2	0.5%
3	0.5%
4	0.5%
5	1.0%
6	0.5 K [NE(dT)]
7	2.4%

Ground IFOV	30 m (Bands 1-5, 7) 120 m (Band 6)
Avg. altitude	699.6 km
Data rate	85 Mbps
Quantization levels	256
Orbit angle	8.15 degrees
Orbital nodal period	98.88 minutes
Scan width	185 km
Scan angle	14.9 degrees
Image overlap	7.6%

Note: The radiometric sensitivities are the noise-equivalent (NE) reflectance differences for the reflective channels expressed as percentages [NE(dP)] and temperature differences for the thermal-infrared bands [NE(dT)] in Kelvins.

4.2.1.1 Tolerance

The TM channels were designed for a NE differential represented by the radiometric sensitivity shown in Section 4.2.1.

4.2.2 Frequency of Calibration

The absolute radiometric calibration between bands on the TM sensor is maintained by using internal calibrators located between the telescope and the detectors that are sampled at the end of a scan.

4.2.3 Other Calibration Information

Relative within-band radiometric calibration, to reduce "striping," is provided by a scene-based procedure called histogram equalization. Because of the absolute accuracy and relative precision of this calibration scheme, it is assumed that any changes in the optics of the primary telescope or the "effective radiance" from the internal calibrator lamps are insignificant in comparison to the changes in detector sensitivity and electronic gain and bias with time and that the scene-dependent sampling is sufficiently precise for the required within-scan destriping from histogram equalization.

Each TM reflective band and the internal calibrator lamps were calibrated prior to launch using lamps in integrating spheres that were in turn calibrated against lamps traceable to calibrated National Bureau of Standards lamps. The absolute radiometric calibration constants in the "short-term" and "long-term" parameter files used for ground processing were modified after launch if there was an inconsistency within or between bands, a change in the inherent dynamic range of the sensors, or a desire to make quantized and calibrated values from one sensor match those from another.

5. Data Acquisition Methods

The BOREAS Landsat TM level-3s and -3p images were acquired through the CCRS. Radiometric corrections and systematic or precision geometric corrections are applied to produce the images in a path-oriented form. A full TM image contains 6,920 pixels in each of 5,728 lines (see Section 11.2). Before any geometric corrections, the ground resolution is 30 m for bands 1-5 and 7 and 120 m for band 6 at nadir. The pixel values of the images can range from 0 to 255. This allows each pixel to be stored in a single-byte field.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

Not applicable.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The BOREAS level-3p Landsat TM images cover the Southern Study Area (SSA) and the Northern Study Area (NSA) . The SSA and the NSA are located in the southwest and northeast portions of the overall region. A full TM scene covers approximately 31,000 square kilometers.

The North American Datum of 1983 (NAD83) corner coordinates of the SSA are:

	Latitude	Longitude
Northwest	54.321 N	106.228 W
Northeast	54.225 N	104.237 W
Southwest	53.515 N	106.321 W
Southeast	53.420 N	104.368 W

The NAD83 corner coordinates of the NSA are:

	Latitude	Longitude
Northwest	56.249 N	98.825 W
Northeast	56.083 N	97.234 W
Southwest	55.542 N	99.045 W
Southeast	55.379 N	97.489 W

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

Before any geometric corrections, the spatial resolution is 30 m for bands 1-5 and 7 and 120 m for band 6 at nadir. These values increase with scan angle away from the nadir path. The level-3p Landsat TM images have had geometric corrections applied so that the spatial resolution for all pixels is 30 m in all bands. These level-3p images have a high level of internal spatial integrity and have had ground control added to improve the accuracy of the geographic coordinates provided on the tape. The accuracy of these geographic coordinates is unknown at the time of writing this document.

7.1.4 Projection

The level-3p Landsat TM images are placed in a Universal Transverse Mercator (UTM) projection based on NAD83. Detailed projection parameter information for the individual images is contained in the leader file(s).

7.1.5 Grid Description

The pixel/grid spacing for each pixel in the level-3p Landsat TM images is 30 m in the UTM projection. Detailed grid parameter information for the individual images is contained in the leader file(s).

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Imagery acquired before the BOREAS field campaigns were conducted is included in the BOREAS archive with imagery collected during the project. Historical Landsat data have been acquired by CCRS routinely since the launch of Landsat 1 and are kept in the CCRS archive.

Since the mid-1980s, CCRS has been acquiring and archiving all Landsat data over Canada during the growing season; however, during the winter, only requested data were obtained. For BOREAS, this policy was modified to obtain data throughout the year over the BOREAS region. The acquired data are archived by CCRS and can be interrogated to ascertain which scenes were archived and their characteristics. The BOREAS level-3p Landsat TM acquisitions cover 20-Aug-1988 to 07-Jun-1994.

There are a limited number of level-3p TM images in BORIS. A few level-3p three-band scenes were ordered specifically to compare precision coordinate information in the header with coordinates derived from the enhanced geographic information BORIS is providing with the level-3a TM product. One seven-band level-3p TM scene is archived in BORIS, only because the level-3s was not available.

7.2.2 Temporal Coverage Map

The following table lists the available level-3p Landsat TM images:

Date	Study Area
20-Aug-1988	NSA
14-Aug-1989	NSA
09-Aug-1991	SSA
07-Jul-1994	SSA

7.2.3 Temporal Resolution

The Landsat TM satellite revisit frequency is 16 days for each path/row; however, in the BOREAS region the overlap between scene paths is about 50%.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The main parameter contained in the image data files is scaled at-sensor radiance.The parameters contained in the inventory listing file on the CD-ROM are:

```
         Column Name
-----------------------------
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM
INSTRUMENT
NUM_BANDS
BAND_QUALITY
CLOUD_COVER
PATH_NUM
ROW_NUM
NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
PLATFORM_ALTITUDE
MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
CRTFCN_CODE
```

7.3.2 Variable Description/Definition

For the image data files:

```
Scaled at-sensor radiance - The scaled value representing the quantized DN derived
                            by the TM scanning systemradiant energy
                            incident on the sensor aperture at the time of data
                            collection in the specific TM wavelength regions.
```

The descriptions of the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
DATE_OBS	The date on which the data were collected.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.
PLATFORM	The object (e.g., satellite, aircraft, tower, person) that supported the instrument.
INSTRUMENT	The name of the device used to make the measurements.

NUM_BANDS	The number of spectral bands in the data.
BAND_QUALITY	The data analyst's assessment of the quality of the spectral bands in the data.
CLOUD_COVER	The data analyst's assessment of the cloud cover that exists in the data.
PATH_NUM	For Landsat and SPOT, the sequential number given to the orbital paths trending from northeast to southwest and extending around the earth.
ROW_NUM	For Landsat and SPOT, the sequential number given to the nominal scene acquisition points along the orbital paths which trend from northeast to southwest.
NW_LATITUDE	The NAD83 based latitude coordinate of the north-west corner of the minimum bounding rectangle for the data.
NW_LONGITUDE	The NAD83 based longitude coordinate of the northwest corner of the minimum bounding rectangle for the data.
NE_LATITUDE	The NAD83 based latitude coordinate of the north east corner of the minimum bounding rectangle for the data.
NE_LONGITUDE	The NAD83 based longitude coordinate of the north east corner of the minimum bounding rectangle for the data.
SW_LATITUDE	The NAD83 based latitude coordinate of the south west corner of the minimum bounding rectangle for the data.
SW_LONGITUDE	The NAD83 based longitude coordinate of the southwest corner of the minimum bounding rectangle for the data.
SE_LATITUDE	The NAD83 based latitude coordinate of the south east corner of the minimum bounding rectangle for the data.
SE_LONGITUDE	The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
PLATFORM_ALTITUDE	The nominal altitude of the data collection plat form above the target.
MIN_SOLAR_ZEN_ANG	The minimum angle from the surface normal (straight up) to the sun during the data collection.
MAX_SOLAR_ZEN_ANG	The maximum angle from the surface normal (straight up) to the sun during the data collection.
MIN_SOLAR_AZ_ANG	The minimum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
MAX_SOLAR_AZ_ANG	The maximum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).

7.3.3 Unit of Measurement

The units for the scaled at-sensor radiance values vary by band. To obtain at-sensor radiance values in Watts/(m^2 * sr * μm) use the formula:

```
At-sensor Radiance = Scaled Value * Gain + Offset
```

where the Gain and Offset values are contained in the ASCII header file.The measurement units for the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Units
SPATIAL_COVERAGE	[none]
DATE_OBS	[DD-MON-YY]
START_TIME	[HHMM GMT]
END_TIME	[HHMM GMT]
PLATFORM	[none]
INSTRUMENT	[none]
NUM_BANDS	[counts]
BAND_QUALITY	[none]
CLOUD_COVER	[none]
PATH_NUM	[unitless]
ROW_NUM	[unitless]
NW_LATITUDE	[degrees]
NW_LONGITUDE	[degrees]
NE_LATITUDE	[degrees]
NE_LONGITUDE	[degrees]
SW_LATITUDE	[degrees]
SW_LONGITUDE	[degrees]
SE_LATITUDE	[degrees]
SE_LONGITUDE	[degrees]
PLATFORM_ALTITUDE	[meters]
MIN_SOLAR_ZEN_ANG	[degrees]
MAX_SOLAR_ZEN_ANG	[degrees]
MIN_SOLAR_AZ_ANG	[degrees]
MAX_SOLAR_AZ_ANG	[degrees]
CRTFCN_CODE	[none]

7.3.4 Data Source

The data contained in the level-3p Landsat TM data files come from various portions of the Landsat satellite, the TM instrument, and the ground processing components. The level-3p Landsat TM images were supplied to BOREAS by the CCRS. The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined by BORIS software from latitude and longitude information contained on the level-3s data files.]
DATE_OBS	[Determined by BORIS software from data and time information contained on the level-3s data files.]
START_TIME	[Determined by BORIS software from data and time information contained on the level-3s data files.]
END_TIME	[Determined by BORIS software from data and time

	information contained on the level-3s data files.]
PLATFORM	[Determined by BORIS software from platform information contained on the level-3s data files.]
INSTRUMENT	[Constant software value]
NUM_BANDS	[Determined by BORIS software from processing of the data files.]
BAND_QUALITY	[Assessed by BORIS personnel from viewing the image.]
CLOUD_COVER	[Assessed by BORIS personnel from viewing the image.]
PATH_NUM	[Determined by BORIS software from location information contained on the level-3s data files.]
ROW_NUM	[Determined by BORIS software from location information contained on the level-3s data files.]
NW_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
NW_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
NE_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
NE_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SW_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SW_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SE_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SE_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
PLATFORM_ALTITUDE	[Determined by BORIS software from platform information contained on the level-3s data files.]
MIN_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MIN_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
CRTFCN_CODE	[Assigned by BORIS based on processing.]

7.3.5 Data Range

The maximum range of scaled at-sensor radiance values in each level-3p Landsat TM image band is limited from 0 (zero) to 255 so that the values can be stored in a single 8-bit (1-byte) field. The following table gives information about the parameter values found in the inventory table on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
DATE_OBS	20-AUG-88	07-JUN-94	None	None	None	None
START_TIME	1703	1721	None	None	None	None
END_TIME	1703	1721	None	None	None	None
PLATFORM	LANDSAT-5	LANDSAT-5	None	None	None	None
INSTRUMENT	THEMATIC MAPPER	THEMATIC MAPPER	None	None	None	None
NUM_BANDS	3	7	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
PATH_NUM	33	37	None	None	None	None
ROW_NUM	21	22	None	None	None	None
NW_LATITUDE	54.76512	56.85902	None	None	None	None
NW_LONGITUDE	-106.14753	-99.00933	None	None	None	None
NE_LATITUDE	54.35433	56.42659	None	None	None	None
NE_LONGITUDE	-103.34489	-96.08501	None	None	None	None
SW_LATITUDE	53.2722	55.37101	None	None	None	None
SW_LONGITUDE	-106.83398	-99.75359	None	None	None	None
SE_LATITUDE	52.87873	54.95749	None	None	None	None
SE_LONGITUDE	-104.124	-96.93001	None	None	None	None
PLATFORM_ALTITUDE	705300	705300	None	None	None	None
MIN_SOLAR_ZEN_ANG	36.1	46.4	None	None	None	None
MAX_SOLAR_ZEN_ANG	36.1	46.4	None	None	None	None
MIN_SOLAR_AZ_ANG	139.3	149.8	None	None	None	None
MAX_SOLAR_AZ_ANG	139.3	149.8	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None

Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the parameter value, but the attempt was unsuccessful.
Unrel Data Value -- The value that indicates unreliable data. This is used to indicate an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation.
Data Not Cllctd -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but

```
                        not identical data sets into the same data base table
                        but this particular science team did not
                        measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A   -- Indicates that the value is not applicable to the respective column.
None  -- Indicates that no values of that sort were found in the column.
--------------------------------------------------------------------------------
```

7.4 Sample Data Record

A sample data record for the level-3p Landsat TM images is not available here. The following are wrapped versions of the records in the level-3p Landsat TM inventory table on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
BAND_QUALITY,CLOUD_COVER,PATH_NUM,ROW_NUM,NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,
NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,PLATFORM_ALTITUDE,
MIN_SOLAR_ZEN_ANG,MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,MAX_SOLAR_AZ_ANG,CRTFCN_CODE
'NSA',20-AUG-88,1703,1703,'LANDSAT-5','THEMATIC MAPPER',3,'GOOD','NONE',33,21,
56.85902,-99.00933,56.42659,-96.08501,55.37101,-99.75359,54.95749,-96.93001,
705300.0,46.4,46.4,149.8,149.8,'CPI'
'NSA',14-AUG-89,1705,1705,'LANDSAT-5','THEMATIC MAPPER',3,'NOT ASSESSED',
'NOT ASSESSED',34,21,56.85336,-100.64357,56.42299,-97.71424,55.36488,
-101.38263,54.95287,-98.55591,705300.0,44.9,44.9,147.1,147.1,'CPI'
'SSA',09-AUG-91,1721,1721,'LANDSAT-5','THEMATIC MAPPER',3,'GOOD','CLEAR',37,22,
54.93235,-106.14753,54.51774,-103.34489,53.44032,-106.83398,53.04264,-104.124,
705300.0,42.4,42.4,142.8,142.8,'CPI'
'SSA',07-JUN-94,1711,1711,'LANDSAT-5','THEMATIC MAPPER',7,'GOOD','CLEAR',36,22,
54.76512,-104.74031,54.35433,-101.9444,53.2722,-105.42017,52.87873,-102.7158,
705300.0,36.1,36.1,139.3,139.3,'CPI'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for level-3p Landsat TM imagery is a full TM scene. The individual level-3p Landsat TM images from CCRS are stored in either a band sequential (BSQ) or band interleaved by line (BIL) form. General information on these two formats is provided in Section 8.2. Detailed information on these formats can be obtained from the CCRS document referenced in Section 17.1. Most of the BOREAS level-3p Landsat TM image products contain only three of the seven bands. BORIS used these three-band images to evaluate the processing of the level-3s images to level-3a products. As such, the number and size of the BIL and BSQ files for the three-band images are less than the full seven-band image format described below.

8.2 Data Format(s)

The CD-ROM inventory listing file consists of numerical and character fields of varying length separated by commas. The character fields are enclosed within single apostrophe marks. There are no spaces between the fields.

8.2.1 Band Sequential Format

The files associated with a BSQ TM scene are as follows:

```
File 1   volume directory
File 2   leader file band 1
File 3   TM band 1
File 4   trailer file band 1
File 5   leader file band 2
File 6   TM band 2
File 7   trailer file band 2
File 8   leader file band 2
File 9   TM band 2
File 10  trailer file band 2
   and so on..
File 21  TM band 7
File 22  trailer file band 7
File 23  null volume file
```

If there are multiple scenes on a tape, the next scene would occupy files 24-46, 23 files exactly as above. Up to four TM scenes (92 files) are contained on one 8-mm tape. Multiple-volume directory files are contained on one tape media because the 8-mm tapes were generated from copying the original 9-track tapes, and each one of those had its own volume directory. Each image file in BSQ format contains image data for one spectral band.

A three-band level-3p TM scene would contain a total of 11 files as described above; however, the bands included in the three-band subset are TM bands 3, 4, and 5.

8.2.1.1 BSQ Leader Files

The contents of leader files, which have been defined in detail by the Landsat Ground Station Operations Working Group (LGSOWG) Technical Working Group (LTWG), are as follows:

- File descriptor record
- Scene header record
- Map projection (scene-related) ancillary record
- Radiometric transformation ancillary record

All leader files contain fixed-length records of 4,320 bytes and contain both ASCII and binary data. For specific details, see the CCRS documentation referenced in Section 17.1.

8.2.1.2 BSQ Imagery File

The BSQ image files have 5,729 records; each record contains 7,020 bytes. The first record in this file is a header record, followed by 5,728 image records.

The contents of the scene header record are specified by LTWG standards and include information relating to the mission, sensor parameters, processing options, and geometric parameters for the sensor.

Each image record contains 32 bytes of prefix data, 6,920 bytes of image data, and 68 bytes of suffix data (32 + 6920 + 68 = 7020). Each image is oriented so that pixel 1, line 1 is in the upper left-hand corner (i.e., northwest) of the screen display. Pixels and lines progress left to right and top to bottom so that pixel n, line n is in the lower right-hand corner.

8.2.1.3 BSQ Trailer File

The trailer file contains information associated with the image data that was not always available before writing the image data, such as data and recording quality and data summaries. Each trailer file contains a file descriptor record and trailer records for all bands of imagery in the associated imagery file. All trailer files contain fixed-length records of 4,320 bytes and contain both ASCII and binary data. For specific details, see the CCRS documentation referenced in Section 17.1.

8.2.2 Band Interleaved by Line Format

At this time, no level-3p Landsat TM data were supplied in BIL format.

9. Data Manipulations

9.1 Formulae

None.

9.1.1 Derivation Techniques and Algorithms

Not applicable.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff processes a level-3p Landsat TM image by :

- Extracting pertinent header information from the level-3p image product and writing it to a disk file.
- Reading the information in the disk file and loading the online data base with needed information.

Some cloud cover and image quality assessment information is generated when BORIS staff processed the level-3p images to level-3a products. This information is entered into the BORIS data base but is not included with the images on tape. To obtain this information, see the inventory file included on the CD-ROMs or see Section 15.1.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

None.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Errors could arise in the acquired imagery from location inaccuracy, distortion of lengths, anisomorphism, the instrument's local coherence, and multispectral registrability. Other errors could arise from inherent radiometric imperfections of the sensors.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Whatever the processing level, the geometric quality of the image depends on the accuracy of the viewing geometry. Spectral errors could arise from image-wide signal-to-noise ratio, saturation, cross-talk, spikes, and response normalization caused by change in gain.

10.2.2 Confidence Level/Accuracy Judgment

Assessment of accuracy of the absolute radiometric constants is difficult. The uncertainties in prelaunch and postlaunch updates of the absolute calibration constants are nominally specified to be less than 10%. A root mean square (rms) summing of known errors in the prelaunch calibration suggests that this may be a reasonable estimate of overall uncertainty in the prelaunch calibration.

There are also known, but as yet uncorrected, effects associated with temperature-dependence of the TM internal calibrator that may be contributing to apparent discontinuous changes at launch and to the continuous changes of gain while in orbit. Additional uncertainties for exoatmospheric reflectances are probably less than 2% in the visible/near-infrared and less than 5% in the shortwave infrared portion of the spectrum as judged by the current differences in estimates of the solar irradiance.

The level-3p Landsat TM images have had geometric corrections applied so that the spatial resolution for all pixels is 30 m in all bands. These level-3p images have a high level of internal spatial integrity and have had ground control applied to give a high level of accuracy to the supplied geographic coordinates.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

The reproducibility of ground measurements at White Sands, NM, at times of Landsat TM overpass to about 5% for five dates for bands 1-4 suggests a potential for monitoring sensor change for the whole system with time. Images are screened for level of cloud cover before BORIS processing.

10.2.5 Data Verification by Data Center

BORIS used developed software to extract information for logging the data into a relational data base. In addition, the software read through the records of the files checking for proper record sizes.

11. Notes

11.1 Limitations of the Data

None.

11.2 Known Problems with the Data

To date, the following discrepancies/problems have been noted in the data:

- Some header files refer to Level-1 rather than Level-3 or to L1P rather than L3P since they were created by software prior to BORIS finalization of data categories.

11.3 Usage Guidance

None.

11.4 Other Relevant Information

None.

12. Application of the Data Set

The level-3p Landsat TM images are useful for anyone interested in high spatial resolution imagery over the entire NSA or SSA.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

BORIS staff developed software and command procedures for:

- Extracting header information from level-3p Landsat TM images on tape and writing it to ASCII files on disk.
- Reading the ASCII disk file and logging the level-3 Landsat TM image products into the Oracle data base tables.
- Converting between the geographic systems of (latitude, longitude), UTM (northing, easting), and BOREAS (x,y) grid locations.

The software mentioned under items 1 to 5 is written in C and is operational on VAX 6410 and MicroVAX 3100 systems at GSFC. The primary dependencies in the software are the tape input/output (I/O) library and the Oracle data base utility routines.

The geographic coordinate conversion utility (BOR_CORD) has been tested and used on Macintosh, IBM PC, VAX, Silicon Graphics, and Sun workstations.

14.2 Software Access

All of the described software is available upon request. BORIS staff would appreciate knowing of any problems discovered with the software, but cannot promise to fix them.

15. Data Access

The level-3p Landsat TM images are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Although the BOREAS level-3p Landsat TM images are being held in a public archive, copyright restrictions limit the distribution and use of the data. The BOREAS CD-ROM series is publicly available and contains some of the level-3a Landsat TM images. However, other Landsat TM image products in the collection are available only to official BOREAS project personnel. Please contact the ORNL DAAC User Services office to get the most recent information.

Users may obtain informaion about the data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

The level-3a Landsat TM data can be made available on 8-mm, Digital Archive Tape (DAT), or 9-track tapes at 1600 or 6250 Bytes Per Inch (BPI).

Although the BOREAS level-3p Landsat TM images are being held in a public archive, copyright restrictions limit the distribution and use of the data. The BOREAS CD-ROM series is publicly available and contains some of the level-3a Landsat TM images. However, other Landsat TM image products in the collection are available only to official BOREAS project personnel. Please contact the ORNL DAAC User Services office (see Section 15.1) to get the most recent information.

16.2 Film Products

None.

16.3 Other Products

Although the image inventory is contained on the BOREAS CD-ROM set, the actual level-3p Landsat TM images are not. See Section 15 for information about how to obtain the data.

17. References

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
ASCII   - American Standard Code for Information Interchange
BIL     - Band Interleaved By Line
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
BPI     - Bytes Per Inch
BSQ     - Band sequential
CCRS    - Canada Centre for Remote Sensing
CCT     - Computer-Compatible Tape
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
DAT     - Digital Archive Tape
DN      - Digital Number
EDC     - EROS Data Center
EOS     - Earth Observing System
EOSDIS  - EOS Data and Information System
```

```
EROS    - Earth Resources Observation System
ERTS    - Earth Resources Technology Satellite
FOLD    - Federally Owned Landsat Database
FOV     - Field of View
FPAR    - Fraction of Photosynthetically Active Radiation
GICS    - Geocoded Image Correction System
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GPS     - Global Positioning System
GSFC    - Goddard Space Flight Center
IFOV    - Instantaneous Field-of-View
I/O     - Input/Output
LAI     - Leaf Area Index
LGSOWG  - Landsat Ground Station Operations Working Group
LTWG    - LGSOWG Technical Working Group
MSS     - Multispectral Scanner
NAD27   - North American Datum of 1927
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NE      - Noise Equivalent
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
rms     - root-mean-square
RSI     - Radarsat International
SBRC    - Santa Barbara Research Center
SSA     - Southern Study Area
TIPS    - Thematic Mapper Image Processing System
TM      - Thematic Mapper
URL     - Uniform Resource Locator
UTM     - Universal Transverse Mercator
```

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If using data from the BOREAS CD-ROM series, also reference the data as:

BOREAS Staff Science, "BOREAS Staff Science Satellite Data Acquisition Program." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

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13. ABSTRACT *(Maximum 200 words)*

For BOREAS, the level-3p Landsat TM data were used to supplement the level-3s Landsat TM products. Along with the other remotely sensed images, the Landsat TM images were collected in order to provide spatially extensive information over the primary study areas. This information includes radiant energy, detailed land cover, and biophysical parameter maps such as FPAR and LAI. Although very similar to the level-3s Landsat TM products, the level-3p images were processed with ground control information, which improved the accuracy of the geographic coordinates provided. Geographically, the level-3p images cover the BOREAS NSA and SSA. Temporally, the four images cover the period of 20-Aug-1988 to 07-Jun-1994. Except for the 07-Jun-1994 image, which contains seven bands, the other three contain only three bands.

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